United States General Accounting Office

GAO

Report to Chairman, Committee on Armed Services, U.S. Senate

March 1992

STRATEGIC DEFENSE INITIATIVE

Estimates of Brilliant Pebbles' Effectiveness Are Based on Many Unproven Assumptions

GAO/NSIAD-92-91

GAO

United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-223094

March 27, 1992

The Honorable Sam Nunn
Chairman, Committee on Armed Services
United States Senate

Dear Mr. Chairman:

This report responds to your request that we review the Strategic Defense Initiative Organization's analyses of the effectiveness of Brilliant Pebbles, the proposed space-based weapon for the Global Protection Against Limited Strikes (GPALS) Strategic Defense System. The report discusses the role of computer simulations in assessing the effectiveness of the Brilliant Pebbles system.

We are sending copies of this report to appropriate congressional committees, the Secretaries of Defense and the Air Force, and the Directors, Strategic Defense Initiative Organization and Office of Management and Budget. We will also make copies available to others.

Please contact me at (202) 275-4268 if you or your staff have any questions concerning this report. Major contributors are listed in appendix II.

Sincerely yours,

Nancy R. Kingsbury

Nancy R. Kingsbury
Director
Air Force Issues

Executive Summary

Purpose

In January 1991, the President directed that the Strategic Defense Initiative (SDI) program be refocused toward providing protection against limited ballistic missile strikes, whether deliberate, accidental, or unauthorized. The proposed system concept is known as Global Protection Against Limited Strikes, or GPALS, and would consist of both surface- and space-based sensors and interceptors. Because this was a significant change in the program, the Strategic Defense Initiative Organization (SDIO) and its contractors are still adapting the SDI program to the directive and are assessing a proposed space-based interceptor system known as Brilliant Pebbles.

The Chairman, Senate Armed Services Committee, requested that GAO examine SDIO's calculation of Brilliant Pebbles' contribution to this new mission and identify the critical assumptions and uncertainties contained in SDIO's analysis of Brilliant Pebbles' effectiveness.

Background

Brilliant Pebbles is a proposed concept that is currently in the early stages of its demonstration and validation phase of development. It entails hundreds of individual interceptors in orbit around the earth at relatively evenly spaced intervals. Each interceptor would be linked by communications to the others and to ground stations. In the event of a ballistic missile attack, each could be given a high degree of autonomy to detect and intercept missiles that enter its battle space.

A set of deployed Brilliant Pebbles, referred to as a constellation, would be made up of several staggered rings orbiting at about 400 kilometers above the earth, with several Brilliant Pebbles in each ring. (See fig. 1.1.) The constellation could be deployed either to provide partial or complete global coverage for detection and interception of ballistic missiles on a continuous basis. Once enabled by human command, the Brilliant Pebbles interceptors could select their targets and divert from their orbits into the path of enemy missiles. The interceptors would carry no explosives, but the force of their high-speed collision is expected to destroy targets.

SDIO's estimates of the overall effectiveness of a Brilliant Pebbles space-based interceptor are based on computer simulations, which at this early stage of the program's development are the only means available to estimate performance of a constellation of Brilliant Pebbles against a ballistic missile attack.

Results in Brief

During this early stage of Brilliant Pebbles' development, SDIO has made extensive use of simulations to answer the question: If SDIO can design, manufacture and deploy a system that functions as planned, will it provide the protection desired? SDIO believes simulations answer that question in the affirmative and uses the results to improve the design.

Congress should be aware, however, of the simulations' limitations. The simulations are still immature and use many unproven assumptions. They do not demonstrate that Brilliant Pebbles can be built and will work. Only later in the development cycle, after Brilliant Pebbles has been fabricated and tested, can the assumptions be replaced with data from testing. SDIO has an extensive test program planned over 5 years to gather data. As testing results replace assumptions, SDIO and Congress can then have increased confidence in the simulations' projections of Brilliant Pebbles' effectiveness.

Principal Findings

Projected Effectiveness Based on Computer Simulations

SDIO's estimates of effectiveness are based on computer simulations of various numbers of interceptors deployed against certain hypothetical ballistic missile attacks. SDIO has identified over 40 hypothetical attack scenarios, or threats, against the United States and its allies, which include short-, intermediate-, and long-range ballistic missile attacks originating from all over the world and submarine launched attacks against the United States. SDIO has investigated many potential deployment schemes to identify a constellation that provides the optimum global protection against all threats. As of December 1991, SDIO had not evaluated through simulations the performance of Brilliant Pebbles against all identified threats. SDIO officials told us subsequently that they completed this evaluation.

Deployment Assumptions Impact Effectiveness

SDIO's computer simulations contain deployment decision assumptions such as the number of Brilliant Pebbles in the constellation and the angle at which the rings cross the equator. Since the refocus to GPALS, SDIO has performed simulations in which the number of Brilliant Pebbles deployed varies from a few hundred to over a thousand. These simulations illustrated that, for most attack scenarios, the effectiveness of a proposed constellation of Brilliant Pebbles improved as the number of Brilliant Pebbles increased. Simulations also indicate that a Brilliant Pebbles

constellation orbiting close to the equator would be more effective against missiles launched from points in the Mid-East or Europe and a constellation orbiting over the North and South Poles would be more effective against attacks from Russia. (See fig. 2.1.)

Simulations Contain Many Assumptions

SDIO makes assumptions about many key operational characteristics of a Brilliant Pebbles constellation, including its ability to provide continuous global surveillance, the length of time it takes for ground control to give a Brilliant Pebbles constellation authority to intercept hostile missiles, the way in which Brilliant Pebbles in the constellation are assigned to targets, and the time delay inherent in the communication system. The accuracy of these assumptions will not be known until testing is completed.

Brilliant Pebbles' performance characteristics are also unproven assumptions because an integrated and operational interceptor has not yet been built and tested. For the purpose of simulations that predict overall constellation effectiveness, SDIO and its contractors assume that each interceptor will perform as specified. SDIO assumptions concerning the performance characteristics of each interceptor include its ability to detect, track, hit, and destroy a hostile missile and its warheads.

Recommendations

GAO is not making any recommendations in this report.

Agency Comments

DOD generally agreed with the information in GAO's draft report. The comments that it provided for emphasis and clarification are included in appendix I. It stressed the importance of using simulations during the demonstration and validation phase and said that the maturity of the simulations will be enhanced as the program proceeds and that assumptions will be modified as more data becomes available.

Contents

Abbreviations

ABM	Anti-Ballistic Missile
DOD	Department of Defense
GPALS	Global Protection Against Limited Strikes
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SSPK	Single-Shot Probability of Kill

Introduction

In March 1983, President Reagan announced his decision to establish an intensive research program aimed at eventually eliminating the threat posed by nuclear armed ballistic missiles. The resulting Strategic Defense Initiative (SDI) Program was chartered in April 1984. The focus of SDI was on the deterrence of Soviet nuclear aggression and reducing our reliance on massive retaliation with nuclear weapons for deterrence.

In January 1991, recognizing changes in the world condition, President Bush directed that the SDI program be refocused toward providing protection against limited ballistic missile strikes, whether deliberate, accidental, or unauthorized. DOD's proposed system for implementing the President's direction is called Global Protection Against Limited Strikes, or GPALS. A GPALS defensive system would consist of both surface- and space-based sensors and interceptors.

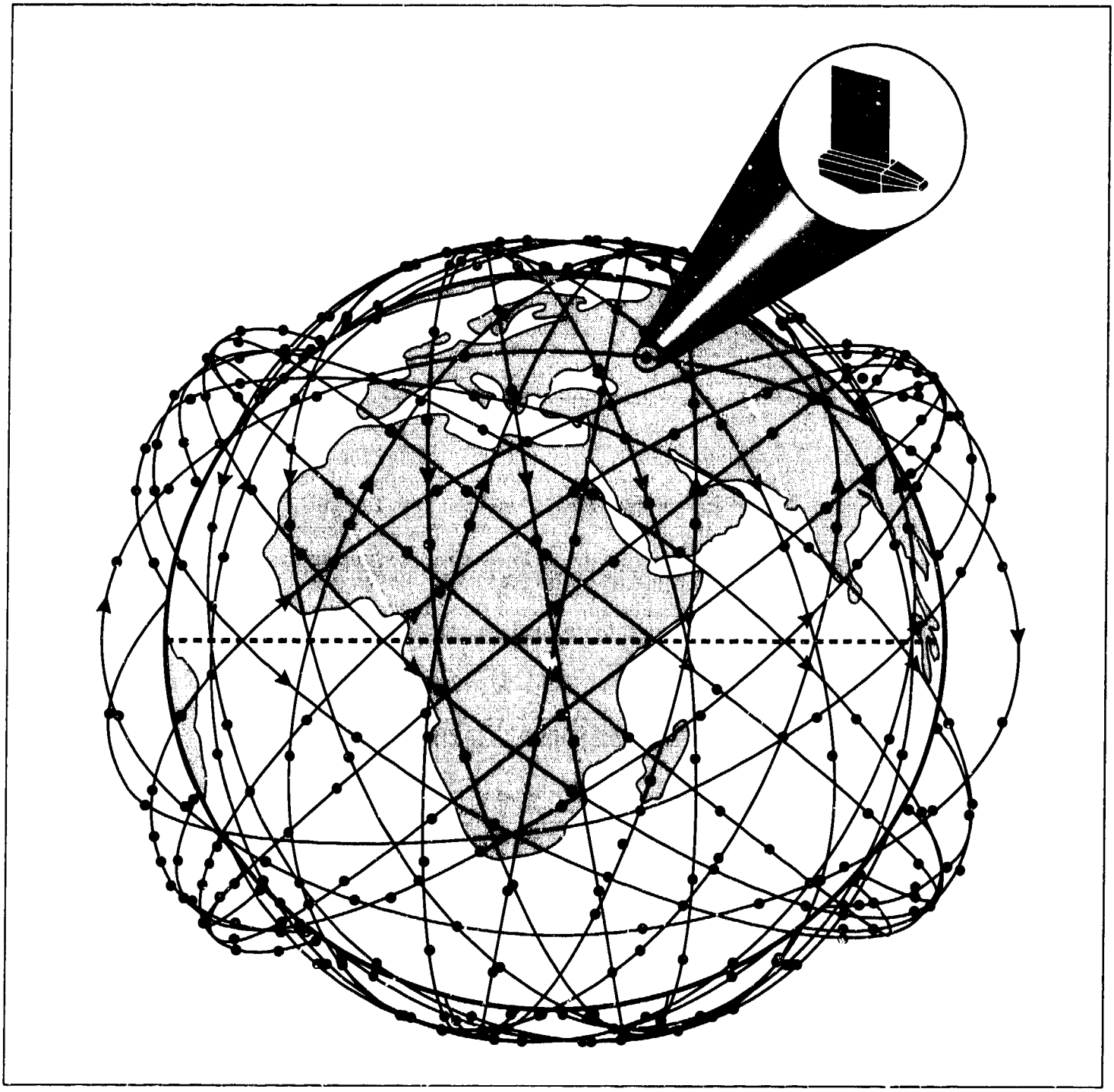
The Strategic Defense Initiative Organization (SDIO) and its contractors are still adapting the program to its new focus. While proposals for a global ballistic missile defense system are evolving within SDIO, Congress has approved an early deployment option to provide protection for the United States that does not include spaced-based interceptors.

Role of Brilliant Pebbles in Global Protection Against Limited Strikes

Brilliant Pebbles is a proposed concept in which hundreds of individual Brilliant Pebbles interceptors would orbit the earth at relatively evenly spaced intervals in a system linked by communications. Each interceptor could be given a high degree of autonomy to detect and attack missiles that enter its battle space.

Brilliant Pebbles would be deployed in space, orbiting at about 400 kilometers (250 miles) above the earth. As shown in figure 1.1, the Brilliant Pebbles constellation would be made up of several orbital rings, with several Brilliant Pebbles in each ring, all traveling at about 5 miles-per-second (a high-velocity rifle bullet travels about a half-mile-per-second).

Figure 1.1: Brilliant Pebbles' Constellation and Orbital Rings



The constellation would be deployed in such a way as to provide continuous global coverage for detection and interception of ballistic missiles. Once enabled by human command, the Brilliant Pebbles could select their targets and divert from their orbits into the path of enemy missiles. The Brilliant Pebbles interceptors would carry no explosives, but the force of their high-speed collision is expected to destroy targets.

The flight of a ballistic missile consists of four stages: boost, post-boost, midcourse, and terminal. The boost and post-boost stages refer to the first few seconds of a missile's flight after launch through the time its warheads, or reentry vehicles, and any decoys are deployed. Midcourse is the relatively long period of time the reentry vehicles and decoys coast along their ballistic trajectories in space. The terminal stage is the final minute or so when the reentry vehicles reenter the atmosphere near their targets.

SDIO is determining how best to implement the President's January 1991 direction to orient proposed missile defenses to provide protection against limited strikes. This involves defining potential ballistic missile attacks, or threats, as well as the mix of ground- and space-based interceptors and sensors, known as the architecture. The SDIO's Systems Architect and his staff have completed the first phase of a study that lays out architectural options to accommodate various funding levels and policy decisions. The SDI program is currently being conducted in compliance with the 1972 ABM Treaty and 1974 Protocol, but SDIO officials have stated that full-scale development of Brilliant Pebbles would require amendment or abrogation of the treaty. Congress has urged the President in the fiscal year 1992 Defense Authorization Act to discuss with the Soviets the feasibility and mutual interests of amending the ABM Treaty. SDIO says the administration has begun this process with the Russian leadership.

In May 1991, the Brilliant Pebbles program entered a 50-month phase to demonstrate and validate Brilliant Pebbles' performance through tests of prototype hardware. SDIO has since extended this phase by 18 months. Current contractor concepts for using Brilliant Pebbles to counter GPALS threat scenarios would require deployment of between 700 and over a 1,000 interceptors.

Role of Computer Simulations in Estimating Potential Effectiveness

SDIO's estimates of overall effectiveness of a Brilliant Pebbles space-based interceptor are based on analytical models and computer simulations.[1] At this stage of the program's development, computer simulations are the only means available to estimate performance of a constellation of Brilliant Pebbles against a ballistic missile attack. Simulations are used extensively by SDIO and its contractors for basic design tradeoff analyses in designing hardware. Because of the program's refocus and the changing ballistic missile threat estimates, SDIO has not compiled the results of all its simulations into one report or document.

Advantages of Computer Simulations

Computer simulations for Brilliant Pebbles are an important, though limited, tool. The ability to investigate questions that could not otherwise be addressed is the main advantage of simulations. They are extremely useful in evaluating systems that do not yet exist or exist only in limited numbers. However, simulations are of necessity based on assumptions and estimates about the design, performance, and availability of technologies for Brilliant Pebbles. These assumptions are by nature simplified and cannot be as complex as reality.

SDIO considers credible simulations to be an important part of early effectiveness assessments that support major milestone decision points in the acquisition process. Moreover, SDIO's reliance on simulations increases as weapon systems become more complex and expensive to test. This is especially true of ballistic missile defenses, where constraints such as cost, safety, the ability to accurately portray threats, and treaty limitations combine to preclude thorough evaluation through field testing alone.

Assumptions Limit Usefulness of Computer Simulations

Although simulations are useful tools, they rely on data that may be incomplete and assumptions that may be inaccurate. Constructing an accurate simulation requires that the behavior of what is being simulated be well understood; there is a great danger in accepting the results of computer simulations as representing reality, rather than using them as design tools. The accuracy of a simulation can only be checked by comparisons with measured results in the real world, a process called "validation." The need for validation was illustrated recently in news accounts of a major air crash.

[1] In this report we will use the term simulation to refer to both analytical models and computer simulations.

An investigation of the crash of a Boeing 767 in Thailand in May 1991 revealed that even a highly sophisticated flight simulator of an operational system was limited by assumptions. The 767 flight simulator initially used to recreate the crash indicated that a pilot could maintain control of the airplane if a thrust reverser accidentally deployed in flight. However, as confirmed by a Federal Aviation Administration official, later data from wind tunnel tests indicated that the simulation software was faulty and had to be revised to accurately represent the aircraft's behavior. After modification, the simulator showed the aircraft rolling onto its back and going into a dive before corrective actions were possible.

SDIO's simulations of the effectiveness of a Brilliant Pebbles constellation are not as mature in their development as a flight simulator. Early simulation results give some confidence that the proposed design of the Brilliant Pebbles and its constellation can function without violating fundamental understandings of physics, geometry, and technology. SDIO's simulations currently assume an interceptor can be developed to meet performance specifications and that developers can overcome the many technology and engineering challenges contained in Brilliant Pebbles' numerous innovative features.

Both the simulations being used and the assumptions made about technical performance contribute to the limitations of Brilliant Pebbles' effectiveness estimates (see chap. 3). DOD has recognized these limitations. In 1987 SDIO commissioned an internal review team to visit contractors using simulations in the design and evaluation of strategic defense systems. The responsible SDIO official said he proposed the study after realizing that the effectiveness results in contractor briefings meant little unless the supporting simulations were fully understood.

The review team examined 10 simulations, some of which have been used to evaluate Brilliant Pebbles, and concluded that none was completely acceptable as a general-purpose evaluation tool. They further concluded that predictions based on simulations were not sufficiently credible to serve as the sole basis for SDI program decisions.

Many Models of Varied Detail Currently Being Used

SDIO and its supporting contractors use many simulations with varying levels of detail to predict effectiveness. For example, SDIO and its contractors use battle engagement simulations, also called "force-on-force" simulations. These represent the performance of the entire Brilliant Pebbles constellation against attacking ballistic missiles and

tabulate results in terms of the number of reentry vehicles intercepted. Battle engagement simulations are used primarily to vary the number of Brilliant Pebbles in a constellation, or to test the effects of different battle management schemes.

Simulations of a single interceptor component or function are at a greater level of detail. For example, simulations may represent how a interceptor would use its sensors to scan the earth looking for ballistic missile launches or how an interceptor would guide itself to a target. SDIO uses these more detailed simulations to build confidence in the results of the overall battle engagement simulations.

Validated and Verified Simulations Are to Be Developed

The accuracy of Brilliant Pebbles' simulations has not been validated by test results or verified by formal reviews of the simulations themselves. However, test results will become increasingly available as the program progresses through the demonstration and validation phase. Currently, SDIO compares various simulation results to assure itself that Brilliant Pebbles' simulations are reasonably accurate.

SDIO refers to formal simulation reviews as confidence assessments. Conducting a confidence assessment is a systematic way of examining the credibility of a computer simulation. In confidence assessments, independent reviewers examine a simulations's conceptual base, determine the validity of the input data, and identify the simulation's limitations.

SDIO funded confidence assessment work through fiscal year 1990. According to SDIO and it contractors, formal confidence assessments were suspended in fiscal year 1991 due to funding constraints and because the architecture for a ballistic missile defense system and the related design features of the interceptor were too dynamic to permit detailed verification of current Brilliant Pebbles' simulation models.

In lieu of formal confidence assessments, SDIO and its contractors compare the results from the simulations done by one group with results from others. Beginning with the Space Based Architecture Study in 1989, SDIO and contractors have used this method to reassure themselves that Brilliant Pebbles' simulations are as accurate as possible at this stage of the program's development. As discussed in chapter 2, SDIO plans to standardize the simulation process.

Objectives, Scope, and Methodology

The Chairman, Senate Armed Services Committee, requested that we identify the critical assumptions of, and uncertainties in, estimates of the effectiveness of Brilliant Pebbles. As agreed to with his office, we limited our work to the effectiveness estimates for a GPALS mission. Our objectives were to examine SDIO's calculation of Brilliant Pebbles' contribution to the GPALS mission and identify critical assumptions and uncertainties contained in SDIO's analyses of Brilliant Pebbles' effectiveness.

We met with officials from SDIO and contractors working on the program. We examined studies of the Brilliant Pebbles to develop information about critical issues that SDIO must address. We also examined studies that discussed implications of the move to a GPALS system. We did not evaluate technical aspects of the Brilliant Pebbles to determine if it would work as specified.

We conducted our work from January through November 1991 in accordance with generally accepted government auditing standards. DOD provided written comments on a draft of this report. Its comments are included in appendix I.

Projected Effectiveness of Brilliant Pebbles Is Based on Computer Simulations

Based on its computer simulations, SDIO believes that Brilliant Pebbles' interceptors would contribute significantly to the GPALS mission of protecting the United States and our allies from limited, unauthorized, or accidental attacks. SDIO estimates that a space-based constellation of between 500 and 1,000 interceptors could have significant intercept capability against a broad class of missiles with ranges longer than 600 kilometers.

Effectiveness Depends on Nature of Ballistic Missile Attacks

To assess effectiveness, DOD must decide on the types and numbers of ballistic missiles the Brilliant Pebbles constellation must intercept. DOD's decision will be based in large part on the input from SDIO's Threat Working Group, which has identified over 40 hypothetical attack scenarios, or threats, including short-, intermediate-, and long-range ballistic missile attacks over the entire globe and submarine launched attacks against the United States. Brilliant Pebbles' effectiveness is contingent on where the ballistic missiles originate, where they are headed, and their positions relative to the orbital positions of the Brilliant Pebbles.

The design of the interceptors would prevent them from entering the earth's atmosphere, and as such, they would have difficulty in countering very short-range ballistic missile attacks because these missiles' trajectories do not go above the atmosphere.

As currently designed, Brilliant Pebbles could not intercept missiles with ranges of less than 400 to 600 kilometers or those with altitudes less than 80 to 100 kilometers. This means that some missiles currently owned by Third World countries could not be attacked by Brilliant Pebbles. However, only a few of the more than 40 threat scenarios identified employ such short-range missiles. Intercepting cruise missiles and aircraft is not part of Brilliant Pebbles' mission.

Deployment Decisions Impact Brilliant Pebbles Effectiveness

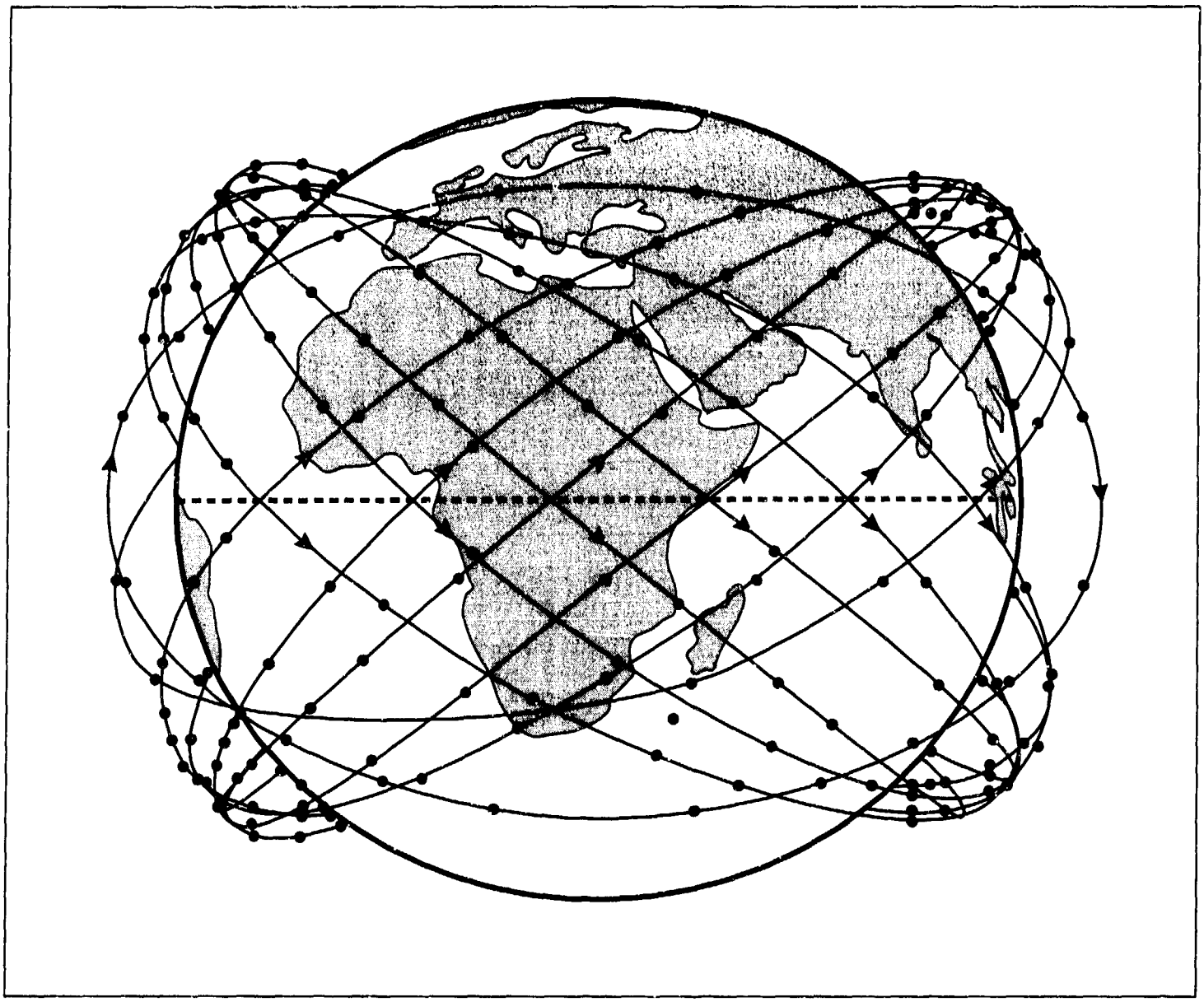
The number of Brilliant Pebbles deployed and the way in which they orbit the earth has a direct effect on the performance of the Brilliant Pebbles constellation against a given threat.

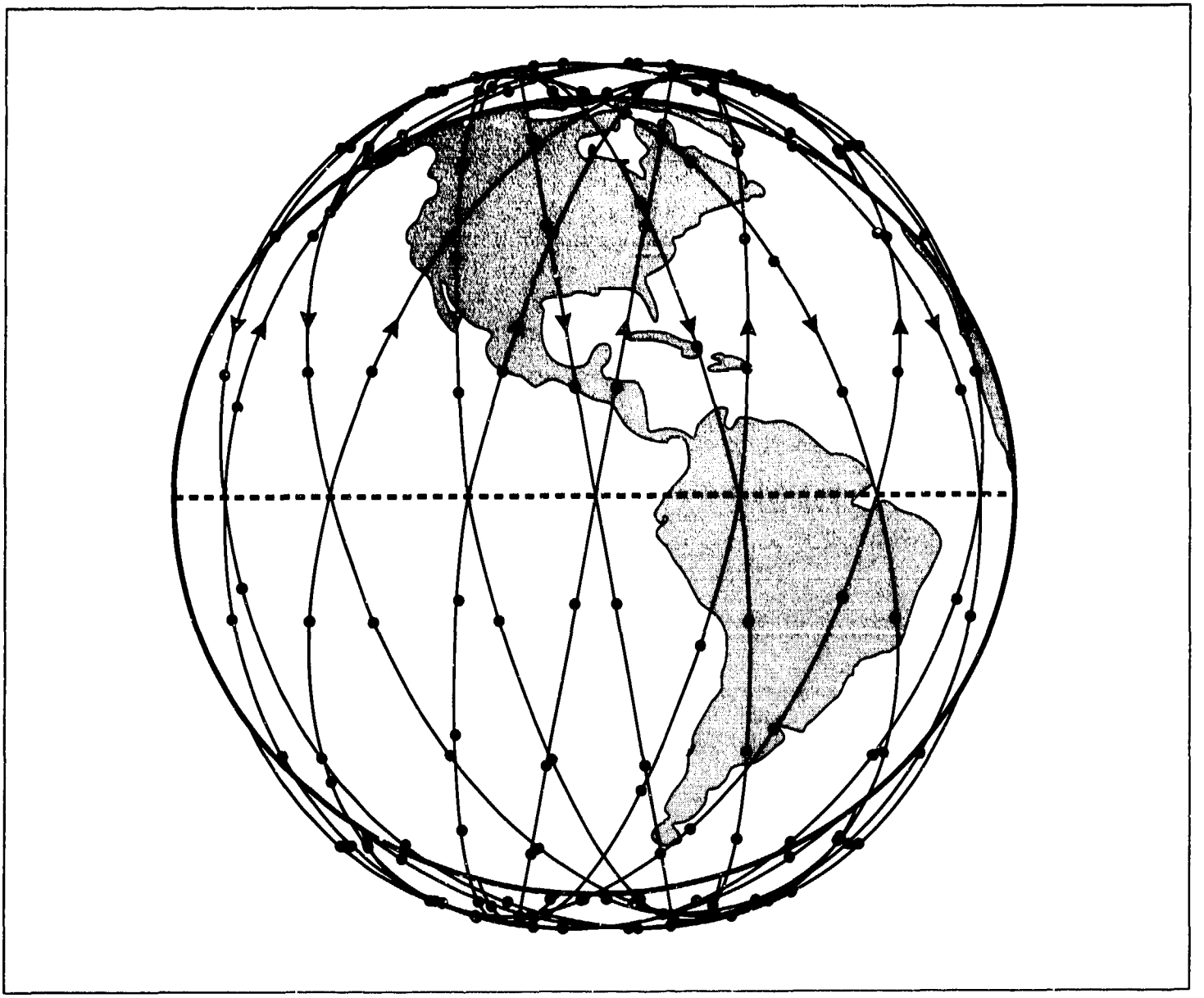
Since the refocus on GPALS, SDIO has performed simulations in which the number of Brilliant Pebbles in orbit varies from a few hundred to over a thousand. These simulations illustrated that for most attack scenarios, the effectiveness of a hypothetical Brilliant Pebbles constellation improved as the number of Brilliant Pebbles in orbit was increased.

The orbital inclination of the Brilliant Pebbles also has a significant effect on performance. Orbital inclination is the angle that the Brilliant Pebbles orbit at in relation to the equator. A ring of Brilliant Pebbles in orbit at the equator would have an inclination of zero degrees and a ring in a polar orbit would have an inclination of 90 degrees.

SDIO's simulations indicate that there are different orbital inclinations that optimize the effectiveness of a Brilliant Pebbles constellation against each of the individual threats. For example, a Brilliant Pebbles constellation in a lower orbital inclination would be more effective against missiles launched from points in the Mid-East or Europe and a constellation in a higher orbital inclination would be more effective against attacks from Russia. However, after the Brilliant Pebbles are deployed, their orbital inclinations cannot be changed. To provide continuous global coverage for both the detection and interception of enemy ballistic missiles, at least a portion of the constellation will most likely be deployed at near-polar orbits.

Figure 2.1: Different Coverage Offered by Different Inclinations





Estimated Effectiveness Based on Computer Simulations

SDIO's estimates of effectiveness were based on computer simulations of Brilliant Pebbles' performance using a certain number of interceptors deployed in a particular constellation against hypothetical threats, such as short-, intermediate-, and long-range, and submarine-launched attacks. As of December 1991, SDIO had not evaluated performance against all the threat scenarios. SDIO told us subsequently that they completed this evaluation.

One type of threat scenario that SDIO did examine was two short-range Al Abbas missile attacks by Iraq. One attack was against the Arabian peninsula, which showed that Brilliant Pebbles would be able to intercept most of the missiles. In the other attack, SDIO ran a simulation showing how Brilliant Pebbles would have performed against the Iraqi missiles launched during Operation Desert Storm. The simulation used Air Force data for 79 of the actual launches, the launch points, aim points, and maximum heights reached by the missiles, and showed that the Brilliant Pebbles constellation in a high orbital inclination would have intercepted about 69 of the missiles.

To estimate Brilliant Pebbles' effectiveness against intermediate-range missiles, SDIO ran a simulation of Brilliant Pebbles' performance against an intermediate-range attack on Great Britain by Libya. It showed that all of the missiles would be intercepted by the Brilliant Pebbles.

Another simulation was run to determine Brilliant Pebbles' effectiveness against a limited Soviet long-range attack using land-based intercontinental ballistic missiles. The simulation showed that Brilliant Pebbles would be able to intercept most of the missiles.

SDIO also ran a simulation to determine Brilliant Pebbles' effectiveness against an attack launched by a submarine off the U.S. coast. It showed that Brilliant Pebbles would be able to intercept almost two-thirds of the missiles launched.

SDIO Plans to Develop Three New Simulations for Brilliant Pebbles

Currently, SDIO and its contractors use many different simulations to estimate Brilliant Pebbles' effectiveness. SDIO plans to standardize the simulation process by requiring each of the two contractors for the Brilliant Pebbles program to design and install a Brilliant Pebbles simulation at the National Test Bed's hub, the National Test Facility in Colorado Springs, Colorado, by 1993. In addition to these two simulations, SDIO and the National Test Bed staff will develop and install a third Brilliant

Pebbles simulation. This simulation is expected to be comprehensive and highly detailed and will serve as a basis for comparison for the two contractors' simulations.

According to SDIO, the two contractors' simulations of Brilliant Pebbles will utilize super-computers, which can process larger amounts of information and thus do more detailed simulations. Most of the Brilliant Pebbles simulations done to date have been run on relatively small computers and some have been modifications of simulations used for other weapons programs such as air-to-air missile systems and the prior Space-Based Interceptor program.

SDIO established an Algorithm Working Group as a way to oversee simulation efforts. It is made up of experts and technical specialists who come together to analyze problems and to review simulations and their underlying performance assumptions. As part of its draft charter, the Algorithm Working Group is to identify problem areas where intensive simulation development efforts are required. The group is also concerned with ensuring that simulations are validated with test results.

Computer Simulations Must Use Unproven Assumptions Due to Early Stage of Brilliant Pebbles Development

The simulations SDIO uses to estimate the effectiveness of Brilliant Pebbles are relatively immature and must use many unproven assumptions about the performance and operation of the constellation. For example, in its simulations SDIO makes assumptions about probabilities that an interceptor will detect, track, collide, and destroy the missile or reentry vehicle. SDIO also assumes that the Brilliant Pebbles constellation will receive timely weapons release authority from a ground station and that the battle management scheme will ensure that the right interceptors will attack the right targets.

As Brilliant Pebbles development progresses, SDIO plans to replace early assumptions about Brilliant Pebbles' performance with data obtained through testing and continued simulation. Ground and space-flight tests will be used to validate performance assumptions for a single, or just a few, interceptors. Computer simulations will continue to be used to predict both the performance of a single interceptor and of an entire constellation of interceptors against various ballistic missile attacks.

Effectiveness Estimates Are Based on Many Assumptions

In addition to assumptions about threat and the configuration of the Brilliant Pebbles constellation discussed in chapter 2, SDIO makes assumptions about other operational characteristics of the constellation and the performance characteristics of each Brilliant Pebbles interceptor.

Simulations cannot prove that the Brilliant Pebbles system will work. Both SDIO officials and contractors stated that only testing can do that. The Director of Integration in the Brilliant Pebbles program office said that most simulations represent only the most basic characteristics of a Brilliant Pebble. The Director of SDIO's Architecture Integration Study stated that the simulations used by his group assume that Brilliant Pebbles will acquire, track, and intercept targets perfectly and the results represent the best that could possibly be expected from a Brilliant Pebbles constellation. According to SDIO, a wide range of assumption values are being used during the early design phase of Brilliant Pebbles to examine potential system performance and sensitivity.

Assumptions Concerning Operational Characteristics

SDIO makes assumptions about the operational characteristics of the Brilliant Pebbles constellation, including continuous global surveillance, the length of time it takes for ground control to give the constellation authority to intercept hostile missiles, the way in which Brilliant Pebbles in the constellation are assigned to targets, and the time delay inherent in the

communication system. The validity of these assumptions has not been demonstrated by testing.

Global Surveillance

One of the requirements for the Brilliant Pebbles constellation is that it provide continuous global surveillance and detection of ballistic missile launches. To determine the best way to meet this requirement, SDIO runs simulations that calculate surveillance coverage based on assumptions about sensor performance characteristics including acquisition range, field of view, resolution of multiple targets, and line-of-sight constraints such as blinding by the sun. Simulations can vary the range at which the sensors detect targets and estimate the effects of the sensors losing targets that are close together or whose tracks cross. For line-of-sight constraints, the cloud cover is set at different altitudes and the sun's blinding effect on certain sensors can also be simulated.

Weapons Release Authority Time Delay

The time it takes for the Brilliant Pebbles constellation to get weapons release authority from ground control is a critical factor. SDIO's simulations show that effectiveness of the constellation decreases as the time required to receive weapons release authority increases. SDIO says these results will have a significant impact on the design of the battle management system. Brilliant Pebbles related command and control simulations, often referred to as war games, have been conducted at the National Test Facility.

Battle Management

Assumptions concerning battle management have an impact on effectiveness calculations. The objective of battle management is to assign interceptors to the right targets based on various strategies, such as maximizing the number of reentry vehicles killed or minimizing over- or under-assignment of Brilliant Pebbles to targets. Battle management decisions can be made by ground control or autonomously by each interceptor based on what it can see and what it knows about the positions of surrounding Brilliant Pebbles.

To perform the battle management function autonomously, the interceptor needs to determine where the target came from, what type of target it is, and where it is headed. The interceptor must also be able to assign a unique label to each missile it sees in order to keep track of many missiles at once. This problem is referred to as correlation, and SDIO contractors continue to work on it. SDIO has identified tracking and target identification as a major technical challenge.

Communications

In many simulations, communications are assumed to be perfect and timely. Communications from the ground to the constellation are performed via a trellis network: a message is passed from the ground to whichever interceptor is in position to receive it. That interceptor passes the message on to its neighboring interceptors, each of which repeats the process until the entire constellation receives the message. SDIO estimates that this process will take only a few seconds.

SDIO has stated that communications from ground control to the Brilliant Pebbles constellation will most likely utilize high-frequency radio signals. However, both radio frequency and laser communication systems are being considered for the space-to-space communication link from one interceptor to another. SDIO considers both the high-frequency radio and laser communication systems to be major technical challenges.

Assumptions Concerning Each Interceptor's Performance

Interceptor performance characteristics are unproven assumptions at this point because an integrated and operational interceptor has not yet been built and tested. For the purpose of overall system effectiveness simulations, SDIO and contractors assume that a single interceptor will perform as specified. SDIO assumptions concerning the performance characteristics of each interceptor include its ability to detect, track, hit, and destroy the target.

Detection and Tracking of Targets

To predict where its target is going, an interceptor must first detect and track it for a number of seconds. However, the longer the interceptor tracks its target, the less time it will have to perform the intercept. Simulations have shown that Brilliant Pebbles' ability to track a target is dependent not only on track time, but also on its position in relation to the target, the speed at which the sensor can process information, and sensor measurement errors. If the interceptor has a large tracking error, it will have greater difficulty intercepting the target.

Interceptor Fly-Out to Target

Target engagement simulations are often broken down into several phases, including most of the interceptor fly-out phase referred to as the mainchase and the final seconds of the fly-out phase referred to as the end-game. Contractors use the most detailed simulations available to analyze these phases.

These simulations are based on assumptions about such propulsion characteristics as how fast the interceptor will fly, how far it can fly, and

how much it can maneuver. Both demonstration and validation contractors have established performance goals for their baseline Brilliant Pebbles designs.[2] According to SDIO, developing an interceptor to meet these goals will be technically challenging.

Single-Shot Probability of Kill

Many of the uncertainties associated with the performance of an interceptor are contained in what is referred to as the single-shot probability of kill factor (SSPK). SSPK represents the probability that a single interceptor has of successfully hitting and destroying its assigned target. For example, an interceptor with a SSPK of .6 would hit and destroy its target, on average, 60 percent of the time while an interceptor with a SSPK of .9 would hit and destroy its target 90 percent of the time.

In many of the simulations done to date, SDIO and its contractors have typically used a SSPK of .8 or .9. In some cases, contractors have used a SSPK of 1 in order to define the best the constellation could do against a given attack.

Contractors told us that the overall estimated SSPK of an interceptor could be lower than .8 or .9. A lower SSPK will result in fewer targets destroyed. SSPK is the product of a number of factors such as the probabilities of the interceptor successfully detecting, tracking, hitting, and destroying a target. For instance, if there were five factors that made up SSPK and each had a value of .9, the resulting SSPK value would be .59, as shown below.

$$SSPK = .9 \times .9 \times .9 \times .9 \times .9$$
$$SSPK = .59$$

Perfect performance is being assumed for some of these factors. For example, the probability that the interceptor will successfully separate and fly away from its lifejacket[3] has been assumed to be 1. In another instance a contractor told us that there were no hardware reliability figures factored into the SSPK he used, which meant that the actual SSPK could be lower.

Target Destruction

In its simulations, SDIO assumes that a hit renders the missile harmless. SDIO believes that Brilliant Pebbles can hit hostile ballistic missiles and

[2]These data are not supplied because they are classified.

[3]The lifejacket houses a single interceptor and its supporting systems.

reentry vehicles, but it does not know if Brilliant Pebbles will in all cases render the target harmless. This problem is referred to as lethality, and it involves where the intercept occurs (preferably over the attacker rather than over the intended target), and how much of the missile's destructive capability is destroyed.

The lethality problem was highlighted in the Gulf War when Patriot ground-based interceptors broke incoming warheads into pieces above their intended targets, but, in some cases, the falling pieces still did considerable damage. DOD is concerned with assuring that nuclear, chemical, biological, or conventional warheads would be destroyed in such a manner as to avoid significant damage from the resulting debris, if any.

SDIO has stated that it needs to do more testing to fully understand Brilliant Pebbles' lethality. The demonstration and validation program is planned to provide a wealth of information on Brilliant Pebbles' actual lethality.

Comments From the Department of Defense

DEPARTMENT OF DEFENSE
STRATEGIC DEFENSE INITIATIVE ORGANIZATION
WASHINGTON, DC 20301-7100

February 26, 1992

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and International Affairs Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

This is the Department of Defense response to the General Accounting Office (GAO) Draft Report entitled--"STRATEGIC DEFENSE INITIATIVE: Estimates of Brilliant Pebbles Effectiveness Are Based on Many Unproven Assumptions," dated February 7, 1992 (GAO Code 392600/OSD Code 8939). Although the Department generally concurs with the report, the following comments are offered for emphasis and clarification.

The use of simulation technology in the development of the Brilliant Pebbles program is most important in evaluating and developing the Brilliant Pebbles hardware. An integrated testing program is established to address the critical technical and operational issues, and the continuing testing efforts will provide validation of simulations and models. Simulations can reduce test costs when used in conjunction with testing in a synergistic combination.

Brilliant Pebbles simulation activities are consistent with a program in the demonstration and validation phase. The "maturity" of Brilliant Pebbles simulations will change and be enhanced with improvement in the design of primary system hardware prototypes. It is crucial that the simulation efforts provide sufficiency to allow the program to proceed to the next milestone.

The report indicates that simulations may rely on data that are incomplete and assumptions that may be inaccurate. That does not limit the simulation usefulness. The Strategic Defense Initiative Organization has relied on an arduous engineering assessment tempered by real-world experience to arrive at a working hypothesis. Assumptions are based upon a combination of the understanding of the system operation, operating characteristics, and engineering analysis. As more data becomes available, assumptions are modified as necessary. Additionally, the Strategic Defense Initiative Organization has relied upon the best available threat information, as found in the most current intelligence scenarios.

It also should be noted that some of the assumptions reflect validated operational requirements. The acquisition

process requires an evaluation of system capability to meet those requirements. The Strategic Defense Initiative Organization does not randomly choose parameters. Operational requirements are matched, to the greatest extent possible, to system performance assumptions. Furthermore, it should be recognized that system effectiveness also is a function of selected tactics and that the user, U.S. Space Command, is deeply involved in the development of operational employment, strategy, and tactics.

In addition, some of the target and lethality comparisons with the performance of the PATRIOT in the Gulf War are not appropriate. Brilliant Pebbles is being designed to intercept so far away from the target that falling debris would not be a problem at the target location. The ability to predict the effects of an interceptor on an incoming missile or missile warhead have not been fully defined and tested for the Strategic Defense Initiative Organization.

The Department of Defense appreciates the opportunity to comment on the draft report.

Sincerely,

HENRY F. COOPER
Director

Major Contributors to This Report

National Security and International Affairs Division Washington, D.C.	Brad Hathaway, Associate Director J. Klein Spencer, Assistant Director Charles A. Walter III, Assignment Manager
San Francisco Regional Office	Frank Graves, Regional Manager Representative Thomas M. Jarnes, Evaluator-in-Charge Kathryn J. Mathisen, Evaluator